Three Years of Ocean Color Instrument Intercomparisons and Cross-Calibrations by the SIMBIOS Project (1997-2000)

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ABSTRACT

The NASA Sensor Intercomparison and Merger for Biological and Interdisciplinary Oceanic Studies (SIMBIOS) Project has a worldwide, ongoing ocean color data collection program, as well as an operational data processing and analysis capability. SIMBIOS data collection takes place via the SIMBIOS Science Team and the National Aeronautics and Space Administration (NASA) Aerosol Robotic Network (AERONET). In addition, SIMBIOS has a calibration and product validation component. The primary purpose of these calibration and product validation activities are to (1) reduce measurement error by identifying and characterizing true error sources such as real changes in the satellite sensor or problems in the atmospheric correction algorithm, in order to differentiate these errors from natural variability in the marine light field; and (2) evaluate the various bio-optical algorithms being used by different ocean color missions. For each sensor, the SIMBIOS Project reviews the sensor design and processing algorithms being used by the particular ocean color project, compares the algorithms with alternate methods when possible, and provides the results to the appropriate project office.

Keywords: SeaWiFS, MOS, OCTS, POLDER, sensor intercomparison, SIMBIOS

1. INTRODUCTION

The SIMBIOS Program was conceived in 1994 as a result of a NASA management review of the agency's strategy for monitoring the bio-optical properties of the global ocean through space-based ocean color remote sensing. At that time, the NASA ocean color flight manifest included two data buy missions, the Sea-viewing Wide Field-of-view Sensor (SeaWiFS) and Earth Observing System (EOS) Color, and two sensors, Moderate Resolution Imaging Spectroradiometer (MODIS) and Multi-angle Imaging Spectro-Radiometer (MISR), scheduled for flight on the EOS-Terra and EOS-Aqua satellites.

Considerable effort was spent by Dr. McClain (Project Scientist) and Dr. Kirk (Study Manager) on examining mission scenarios for EOS Color because of the scheduling delays being encountered with SeaWiFS. However, with the delay of SeaWiFS and an uncertain launch schedule, it was not clear that EOS Color was needed to fill a potential gap between SeaWiFS and MODIS, especially when five additional ocean color systems with similar global capabilities [Ocean Color and Temperature Sensor (OCTS); Global Imager (GLI); Polarization Detecting Environmental Radiometer-1 (POLDER-1) and -2; and Medium Resolution Imaging Spectrometer (MERIS)] and several other non-global missions by Argentina, Germany, Taiwan, India, Korea, the U.S. Navy, and the People's Republic of China, were planned for launch during the late 1990s.

The review led to a decision that the international assemblage of ocean color satellite systems provided ample redundancy to assure continuous global coverage, with no need for the EOS Color mission. At the same time, it was noted that non-trivial technical difficulties attended the challenge (and opportunity) of combining ocean color data from this array of independent satellite systems to form consistent and accurate global bio-optical time series products. Thus, it was announced at the October, 1994 EOS Interdisciplinary Working Group meeting that some of the resources budgeted for EOS Color should be redirected into an intercalibration and validation program. NASA Goddard Space Flight Center (GSFC) was directed to develop a plan for submission to NASA Headquarters (HQ) by May 1995. As a result of the directive from NASA/HQ, the ocean color group lead by Dr. McClain at NASA/GSFC organized an international organizational meeting in February 1995 at the University of Miami Rosenstiel School for Marine and Atmospheric Sciences. The objective was develop a conceptual plan for a comparison program. The "Ocean Color Multisensor Data Evaluation and Utilization Plan" (http://simbios.gsfc.nasa.gov/ under SIMBIOS Documents) outlined NASA's contribution to the international effort was completed, submitted, externally reviewed, and revised in 1995.

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Based on the final plan, the first NASA Research Announcement (NRA) was released in July 1996, and the SIMBIOS Project Office was established at NASA's Goddard Space Flight Center (GSFC) in January 1997 (co-located with the SeaWiFS Project). The initial SIMBIOS Program was scoped for five years (1997-2001) and included separate support for a science team (NRA selections) and the Project Office. Dr. Mueller (San Diego State University) acted as an interim project manager at NASA/GSFC under a one-year assignment to assist in getting the project office organized and the science team contracts executed. His assistance in this capacity was essential as the SIMBIOS Project was beginning just as the SeaWiFS Project was preparing for launch.

In parallel with the NASA SIMBIOS Program planning, the international effort was being organized. The initial meeting was held in Victoria, British Columbia during September, 1995. As a result of the recommendations from that meeting, the International Ocean Colour-Coordinating Group (IOCCG) was formed (http://www.ioccg.org/). The IOCCG presently operates under the auspices of the Scientific Committee on Oceanic Research (SCOR) and chairmanship of Dr. Platt (Bedford Institute of Oceanography). The IOCCG meets one or two times per year and is generating a series of special reports on topics essential to the coordination of the international ocean color community (e.g., IOCCG, 1998).

During the second year of the SIMBIOS Project, Dr. McClain assumed project management of both the SeaWiFS and SIMBIOS as both Dr. Cleave and Dr. Mueller stepped down in their roles as project managers of these two projects, respectively. In Fall 1998, Dr. Fargion was hired as Deputy Project Manger to assist Dr. McClain. Many positions are shared or co-funded by SeaWiFS because the nature of some tasks are common to both projects, yet do not require a full time person for each, e.g., the educational outreach and science support coordinator. The SIMBIOS Project Office, co-located with the SeaWiFS Project Office, provides support and coordination for the SIMBIOS Program such as administration, project documentation, and interagency and international coordination. It also incorporates aspects of instrument calibration, measurement protocol experiments, round robins, algorithm development and evaluation, product merging, and data processing (Figure 1).

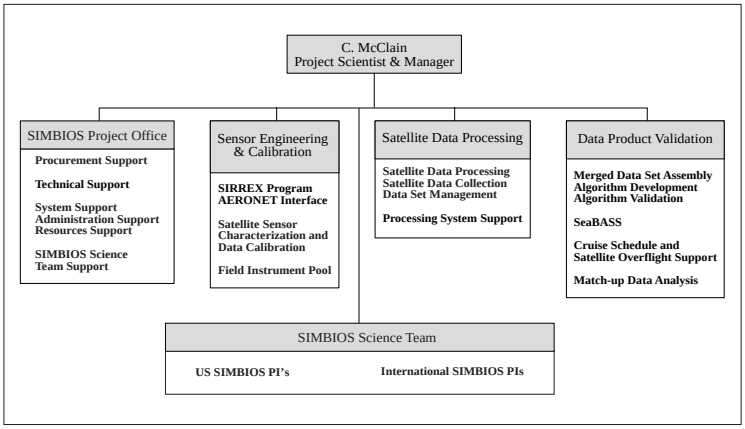

Figure 1. SIMBIOS Project Organization Chart

The specific objectives of the SIMBIOS Program are: (1) to quantify the relative accuracy of measurements from the ocean color products from each mission, (2) to work with each project to improve the level of confidence and compatibility among these products, and (3) to develop methodologies for generating merged level-3 products. SIMBIOS has identified the primary instruments to be used for developing global data sets. These instruments are SeaWiFS, OCTS, POLDER (ADEOS-I and II), MODIS (Terra and Aqua), MISR, MERIS, and GLI. The products from other missions (e.g., OCI and the two MOS sensors) will be tracked and evaluated, but are not considered as key data sources for a combined global data set.

In order to better communicate with the ocean color community, the Project expanded its web site (http://simbios.gsfc.nasa.gov) to include, among other things, monthly reports of the Science Team investigators. The SIMBIOS web site is organized to serve as the main information resource to access the Project activities, Project Office and Science Team. The web site is organized under five main topics: News and Information, Support Services and Schedule, Project Status, Instrument Pool, SeaBASS and Contacts. All sections are updated as needed and Project TM's are posted. The Project Office, in an effort to educate and promote the concept of an organized program of sensor cross-calibration and

validation, sends representatives to several international conferences. Many of the original objectives of SIMBIOS are discussed in more detail in the SIMBIOS Project 1998 Annual Report[1] and in the SIMBIOS Project 1999 Annual Report[2].

2. SIMBIOS SCIENCE TEAM

The Science Team is selected through NRA's 1996 and 1999. NASA HQ manages the process of team selection, but the GSFC NASA Procurement Office handles the team contracts, work statements and, if necessary, budget negotiations. The Project funds numerous US investigators and collaborates with several international investigators, space agencies (e.g., NASDA, CNES) and international organizations (e.g., IOCCG, JRC). US investigators under contract provide *in situ* atmospheric and bio-optical data sets, and develop algorithms and methodologies for data merger schemes. NASA Procurement requires formal evaluations for all contracts at the end of each contract year. These evaluations are to go into a database and are shared with the PI's institution or upper management. The locations of specific SIMBIOS team investigations are shown in Figures 2 and 3.

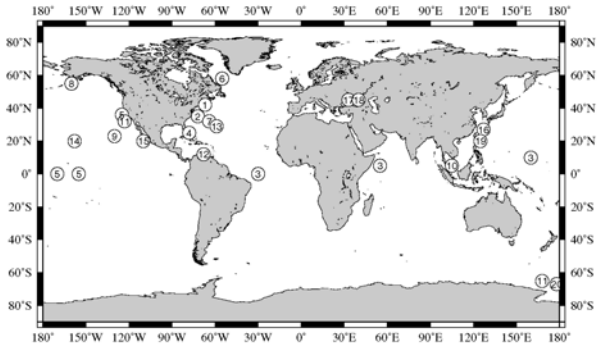

Figure 2. Global distribution of the NRA-96 selected SIMBIOS studies. United States (field): (1) Balch; (2) Brown/Brock; (3) Capone/Carpenter/Subramaniam and Miller; (4) Carder and Green; (5) Chavez; (6) Cota; (7) Dickey; (8) Eslinger; (9) Frouin; (10) Miller; (11) Mitchell and Green; (12) Müller-Karger; (13) Siegel; (14) Porter (15) Zaneveld and Mueller. United States (theoretical): Flatau; Siegel and Stamnes/Chen. International: He; Korotaev; Kopelevich; and Li.

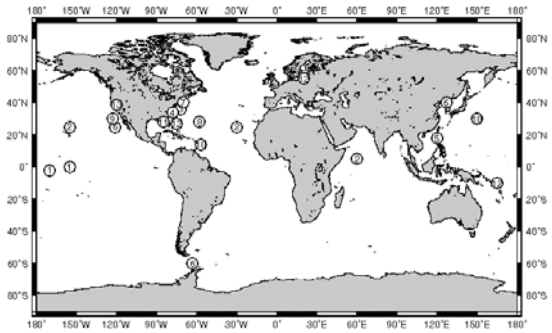

Figure 3. Global distribution of the NRA-99 selected SIMBIOS studies. United States (field): (1) Chavez; (2) Frouin; (3) Gao; (4) Harding; (5) Miller; (6) Mitchell; (7) Morrison; (8) Nelson; (9) Siegel; (10) Spinhirne; (11) Stumpf; (12) Subramaniam; (13) Zalewski. United States (theoretical): Gregg; Hooker; Maritorena; Mueller; Trees and Wang. International: Bohm; Zibordi; Fougnie; Deschamps; Antoine; Kopelevich; Ishizaka; Fukushima; Chen; Li; He and Tang.

The international ocean color community response for the NRA-99 was overwhelming a total of 75 PI's proposed collaboration with the Project. The twelve international proposals cover topics ranging from protocols, calibration-validation activities, atmospheric-biological algorithms, and data merging. The SIMBIOS Science Team (NRA-96) meetings were held

in August 1997 at Solomons Island (Maryland), in September 1998 at La Jolla (California) and in September 1999 at Annapolis (Maryland). Nearly all Science Team members, US and international, were in attendance or were represented by one of their staff. Also, the IOCCG was invited, and most attended or sent representatives. During each year the Project Office has fostered several international collaborations. The Project provided partial or as-needed travel support for international participants to team meetings or to collaborate with the project on specific topics.

3. OCEAN COLOR SATELLITE DATA PROCESSING

One of the primary goals of the SIMBIOS Project is to develop methods for meaningful comparison and possible merging of data products from multiple ocean color missions. Direct comparison of such products is complicated by differences in sensor characteristics and processing algorithms, as well as spatial and temporal coverage. The Project conducted extensive studies[3,4,5 and 6] of the calibrations and derived products from the OCTS the POLDER instrument, and the MOS. In all cases, the work was in collaboration with instrument team members associated with the respective missions.

The present approach used by the SIMBIOS Project Office (Table 1) is to develop a Level-1b to Level-2 software package (MSl12) which is capable of processing data from multiple ocean color sensors using the standard SeaWiFS atmospheric correction algorithms of Gordon and Wang [7, 8]. The integration of a new sensor into MSl12 involves the development of a set of input functions and derivation of band-pass specific quantities such as Rayleigh scattering tables and Rayleigh-aerosol transmittance tables. Once the processing capability has been established, the vicarious calibration can be tuned using match-up data from the MOBY site and/or cross calibration with another sensor. The SIMBIOS Project can thereby provide a completely independent assessment of instrument calibration and sensor-to-sensor relative calibration. The Project is also able to provide insight to the sensor team in understanding how differences in calibration techniques and atmospheric correction algorithms propagate through the processing to produce differences in the retrieved optical properties of the water.

Table 1

CURRENT SIMBIOS LEVEL -2 PROCESSING APPROACH
• Multi-sensor Level 1B to Level 2 software package • Software currently able to process MOS, SeaWiFS, OCTS and POLDER • With reprocessing #3 the software is the SeaWiFS production code (possible multiple code comparisons in future) • Identical atmospheric correction algorithm used for all sensors • Common ancillary data sources for all sensors and match-up analyses

MOS Data

On 27 February 1999, the SIMBIOS Project began operating a receiving station at NASA's Wallops Flight Facility (WFF) to acquire data from the German Modular Optoelectronic Scanner (MOS) onboard the Indian IRS-P3 spacecraft. The data from the Wallops ground station are processed at NASA's Goddard Space Flight Center, with routine distribution of Level-0 datasets to the German Remote Sensing Data Center (DLR-DFD). After a pass is acquired at Wallops, the raw files are transferred to the SIMBIOS Project at NASA's Goddard Space Flight Center via an automated FTP process. The raw files are then converted to level-0 format through a software package provided by ISRO. Work with MOS included the following:

- Completion of an evaluation of the MOS on-orbit calibration[5,6], navigation and level-2 processing code. A MOS processing module has been incorporated into SeaWiFS Data Analysis System (SeaDAS).
- All MOS data collected at Wallops Flight Facility (WFF) can be browsed and ordered from the SIMBIOS Project.

OCTS Data

From measurements of the MOBY buoy and from other sites by OCTS, vicarious calibration coefficients have been derived by the NASDA ocean color team and by the SIMBIOS Project[1,2]. Considering that the two projects use different atmospheric corrections[9] and different *in situ* measurements for calibration, the two sets of results are in very good agreement[2]. The largest difference is in the 765nm band, which NASDA does not use for atmospheric correction, but which SIMBIOS uses and corrects for oxygen absorption. Work with OCTS included the following:

- Match-up comparisons between field and OCTS data used subscenes provided by NASDA. Vicarious calibration of the OCTS was performed using *in situ* data from the MOBY buoy. Two validation analyses were performed: a comparison of OCTS data processed by SIMBIOS to *in situ* measurements obtained from the SeaBASS data set.
- Completion of level-0 and -2 processing of all OCTS data collected at the WFF. The data were processed using compute programming code developed within the SIMBIOS Project Office. This code was made available to the ocean color user community via the SeaDAS [10]. The data products can be displayed using a browser and were left online for the user community to download for nearly eight months.
- Furthermore, Gregg et al.[11] assessed geometric and radiometric performance of a limited set of OCTS data from the US East Coast and the Gulf of Mexico. Results indicated a geometric offset in the along-track direction of 4-5 pixels that was attributed to a tilt bias, but radiometric stability was inconclusive due to daily variability. Comparison with co-located *in situ* measurements showed that the pre-launch calibration required adjustment from -2% to +13%[11].

POLDER Data

During the Spring of 1999 the SIMBIOS Project began collaborations with scientists from CNES and the University of Lille (France). Using the same MOBY data set, CNES and SIMBIOS personnel performed a vicarious calibration of POLDER using CNES and SIMBIOS processing software, respectively, and achieved similar results. Work with POLDER consists of both satellite data analysis and evaluation of *in situ* data from SIMBAD. SIMBAD is an instrument designed to collect above-water reflectance data and is the primary field instrument used by the POLDER science team for validation. Joint papers are anticipated from this collaboration, and the SIMBIOS Project plans to implement POLDER processing within SeaDAS[10]. POLDER activities include the following:

- Evaluations of the Rayleigh radiance tables used for operational POLDER processing and the POLDER science team's methods for vicarious calibration.
- Comparison of level-2 products generated by the SIMBIOS Project and by CNES with *in situ* data. As with OCTS, MOBY was used for vicarious calibration of the visible bands.

4. VALIDATION OF BIO-OPTICAL PROPERTIES

Having a standard set of measurement protocols is indispensable in developing consistency across the variety of international satellite ocean color missions either recently launched or scheduled for launch in the next few years. In the U.S., for instance, ocean color validation support is derived from four separate funding programs, i.e., the SeaWiFS Project, MODIS validation program, the EOS calibration and validation program, and the SIMBIOS Project[1,2]. While each mission has its own validation effort, the mission validation teams should not need to define separate validation measurement requirements. The SeaWiFS and SIMBIOS Project have allocated resources to describe and develop protocols or scientific approaches in accordance with the goals of the Projects. These NASA TMs are intended to provide standards, which if followed carefully and documented appropriately, will assure that any particular set of optical measurements will be acceptable for ocean color sensor validation and algorithm development[12,13]. These protocols are guidelines and may be somewhat conservative. Continued development and refinement of these protocols help ensure coordination, collaboration, and communication between those involved.

The SIMBIOS Project has an extensive set of *in situ* data for match-up analysis from the SeaBASS database, which is presently comprised of data from over 250 cruises and includes 400,000 pigment records (Figure 4). The *in situ* data in SeaBASS include measurements of water-leaving radiance and other related optical and pigment measurements, from ships, moorings and drifters. Various methods are deployed to collect of SeaBASS data, including the use of subsurface and above-water measurement devices[12,13, 14]. SeaBASS data are used by the SIMBIOS Project to validate SeaWiFS and other (OCTS, POLDER, etc.) post-launch imagery and to develop new operational chlorophyll algorithms. The SIMBIOS L_{wn} and chlorophyll a matchup procedure and analysis are described in Bailey et al[15]. Presently, SeaBASS data sets include data from calibration round robins, the SeaWiFS pre-launch calibration and characterization data and a large number of bio-optical data sets for product validation and algorithm development.

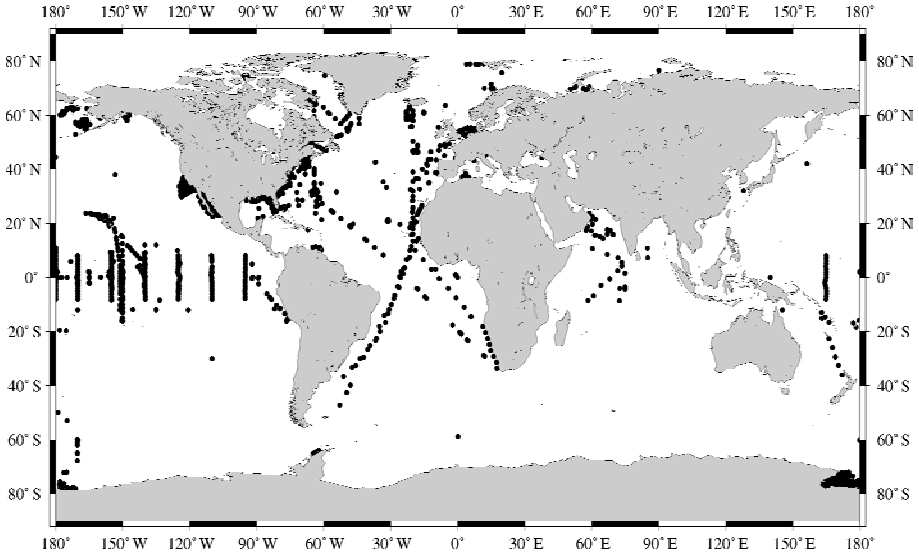

Figure 4. Bio-optical & atmospheric *in situ* data submitted to SeaBASS (1/1998-6/2000)

A redesign of the SeaBASS database[13] started in Fall 1999, which is expected to be operational in Fall 2000. Changes to the database include (1) an increase in the number of tables to improve data normalization and database performance, (2) a reconfiguration of the system to take advantage of multiple computer processors and increased physical storage space, (3) the generation of stored procedures and tables for internal SIMBIOS Project Office accounting activities, and (4) the ability to ingest bio-optical and pigment data into tables within the database. The latter will allow specific data values to be extracted by performing simple keyword searches on the metadata or by applying range conditions (e.g. waveband, depth, etc.) on the data tables. A current description of the SeaBASS system is available at http://seabass.gsfc.nasa.gov.

5. SUPPORT SERVICES

In an effort to improve the quality and quantity of calibration and validation data sets, the SIMBIOS Project offers several support services to field investigators. These services include; scheduling of on-board LAC recording for SeaWiFS; overflight predictions for operational sensors (currently SeaWiFS, OCTS, MOS-B, and MODIS); near real time SeaWiFS imagery for cruise locations; and optical instrumentation from a pool of investigator- and project-owned instruments.

Scheduling SeaWiFS On-board LAC Recording

Since much of the world's oceans are not covered by a SeaWiFS HRPT station, high-resolution data may be recorded onboard the SeaWiFS sensor. As a service to the science community, the SIMBIOS Project, in conjunction with the SeaWiFS Project, can schedule SeaWiFS onboard LAC for cruises that occur outside HRPT coverage. SeaWiFS has the ability to record a maximum of 10 minutes of high-resolution data per downlink. Typically, a 30-second interval is allotted for LAC target, which corresponds to 180 scan lines or approximately 200 km along track at nadir. Detailed information on LAC scheduling is available on the SIMBIOS web site.

Near Real Time SeaWiFS Imagery

In addition to providing predictions for satellite over-flight times, the SIMBIOS Project offers near real time imagery of the operational SeaWiFS products in JPEG format to cruises at sea. These images provide field investigators with additional information with which they may maximize *in situ* sampling of transient oceanographic features. The default specifications for the images provided include:

- available LAC, HRPT, and GAC
- chlorophyll a and pseudo-true color images
- 2^0 box about a designated location or the entire designated region; image width of 600 pixels
- minimum percent valid chlorophyll pixels: 5%

Images may be customized to best accommodate individual investigators needs. Detailed information on near real time imagery is available on the SIMBIOS web site.

Overflight Predictions for Operational Sensors

For calibration and validation purposes, in situ measurements should be made as close to the sensor over-flight time as is possible. To aid investigators in determining when sampling should occur, the SIMBIOS Project offers over-flight predictions for all operational ocean color remote sensors. Currently, the sensors supported are SeaWiFS, MOS-B, OCI and MODIS. Detailed information on over-flight predictions is available on the SIMBIOS web site.

Satellite Data

The SIMBIOS Project collected OCTS data for the East Coast of the United States while the ADEOS satellite was operational. These data have been processed using computer program code developed in house and are available through a browse utility linked to the SIMBIOS Project's web site. The Project also routinely collects MOS data for the East Coast of the U.S. while the instrument is in ocean viewing mode. As with the OCTS data, these data are made available to the public via the SIMBIOS Project web site.

Support for Field Operations

During the first three years of SeaWiFS operations, the SIMBIOS Project provided support over 200 cruises (Table 2). Support can include orbit analyses for cruise track planning, as well as real-time image data sent directly to the vessel. During 1999, the SIMBIOS Project also initiated an effort to participate on at least one field deployment with each SIMBIOS Science Team member during the three-year period of performance.

6. SENSOR ENGINEERING AND CALIBRATION

Instrument Pool

The SIMBIOS Project provided funding to several of the NRA-96 science team members for the purchase of *in situ* ocean optical instrumentation. The funding was provided with the stipulation that these instruments would be made available for three years (1997-2000) to an instrument pool to be maintained by the Project Office. These instruments will be returned to the science team members and will be not available after the year 2000. The SIMBIOS Project has a sun photometer instrument pool available for the new science team (NRA-99). The pool consists of 12 MicroTops hand-held sun photometers, 2 PREDE sun photometers (Japan), 2 SIMBAD and 2 SIMBADA sun photometers developed by the Laboratoire d'Optique Atmospherique (LOA, France) and 1 micro-pulse Lidar.

In addition to the sun photometers instrument pool, the SIMBIOS Project takes advantage of the existing Aerosol Robotic Network (AERONET) which is dedicated to monitoring aerosol optical thickness around the globe. Because most of the sun photometers used within the AERONET[16] project are in continental zones, the SIMBIOS group enhanced this network with island and coastal stations. The 13 hardened CE318 CIMEL instruments are designed to better withstand the corrosive marine environment. SIMBIOS CIMEL sites include Lanai Hawaii (with backup in Honolulu), Ascension Island, Bahrain, Papeete (Tahiti), Wallops Island (USA), Anmyon (South Korea), Erdemli (Turkey), Horta (The Azores), Puerto Madryn (Argentina) and soon Perth (Australia). The remaining two SIMBIOS CIMELs, one as a backup, are deployed at Goddard Space Flight Center. Cruise experiments handled by various SIMBIOS investigators allow collecting *in situ* measurements from hand-held and shipboard sun photometers with the augmented AERONET network provide the Project with global data sets.

Calibration

Sun photometers and sky radiometers are routinely calibrated at GSFC calibration facility by the Project. Equipment developed at the University of Lille (France) for the calibration of polarized channels in the sun photometers was purchased and installed at the GSFC calibration laboratory and shared by the AERONET group. The calibration of the sun photometers was described in the project annual reports[1,2]. Details on instrument operation, calibration and the theoretical principles are posted at the SIMBIOS web page. The SIMBIOS Project has implemented its own correction strategy[17, 18] for converting instrument voltages to aerosol optical thickness (AOT). The approach ensures a uniform AOT processing for all instruments making the AOTs comparable for the SIMBIOS sun photometers, as well as between instruments and satellite sensor AOTs derived by means of the atmospheric correction. Also, the method uses a consistent set of tuning variables, such as ancillary

data, concurrently applied for the correction of satellite radiances. Therefore, some stages of the satellite and *in situ* data processing are identical, which beneficially contributes to confidence in the match-ups[19, 20, 21]. The Project is continuing its effort in comparing and validating the SeaWiFS (and soon other missions, as well) aerosol optical products with *in situ* measurements. SeaWiFS has a tendency of overestimating aerosol optical thickness with respect to the *in situ* measurements [19, 20, 21]. For the aerosol measurement bands of satellite sensors that cannot be vicariously calibrated by other means[22], these AOT measurements provide a very good means for checking sensor performance.

Calibration Round Robin

The first SeaWiFS Transfer Radiometer (SXR) was built for the SeaWiFS Project to verify and compare measurements of spectral radiance at six discrete wave lengths in the visible and near infrared[24]. In addition, SXR is used to compare these sources to standards of spectral radiance maintained at the National Institute of Standards (NIST). SIMBIOS Project had a second copy of the SeaWiFS Transfer Radiometer (SXR-II) built for use in the calibration round robin. This unit will supplement the first unit and is designed for easier travel. NASA personnel carried out the first SeaWiFS-SIMBIOS Intercalibration Round-Robin Experiment (SIRREX-6) from August 1997 to February 1998. SIRREX-6 was performed in a completely different manner from SIRREX-1 through SIRREX-5. In those tests, laboratory references were brought to a central location and tested one against another. In SIRREX-6, the same four common field instruments (e.g., Satlantic in-water radiometers) were taken to nine separate laboratories and tested using the laboratories' standards and procedures. Two of the sensors were seven-channel radiance heads and two were seven-channel irradiance heads. The calibration and data reductions procedures used at each site followed that laboratories' normal procedures. The reference lamps normally used for the calibration of these types of instruments by the various laboratories were also used for this experiment. NASA personnel processed the data to produce calibration parameters from the various laboratories for comparison. These tests showed an overall agreement at better than the +/-2% level. Test equipment, calibration procedures, data reduction, and specific handling procedures have been published in the Riley and Bailey[24]. During 1999, the SXR was involved in intensive round robin of AVIRIS at the NASA JPL. The SXR-II is currently being characterized and calibrated. It will be used in future SIRREX round robin experiments starting in Winter 2000.

Chlorophyll a Round-robin activity started in winter 1999 and was been designed to evaluate the differences in fluorometric and high performance liquid chromatography (HPLC) pigment analyses between several U.S. laboratories presently providing data to the Project. Final results are expected in Winter 2000.

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Table 2. SIMBIOS major cruises supported with services provided.

Cruise Location	Begin Date	End Date	On-board LAC	Over-flight Prediction	Near Real Time Imagery	Instrument Pool	Principal Investigator
Chesapeake Bay	09/28/1997	11/23/1997	√				Curt Davis
Black Sea	10/03/1997	10/13/1997		√			Oleg Kopelevich
Alaska	10/10/1997	10/17/1997				√	Glenn Cota
Gulf Of Maine	11/10/1997	11/21/1997		√	√		Barney Balch
Taiwan	11/23/1997	11/25/1997	√	√			Hsien-wen Li
Equatorial Pacific	09/27/1997	12/16/1997	√	√			Francisco Chavez
Ross Sea	10/01/1997	12/14/1997	√	√	√		Greg Mitchell
Equatorial Atlantic	11/14/1997	12/12/1997	√	√	√		C. Menkes
HOTS	12/01/1997	12/21/1997	√	√			John Porter
Jamstec / Kaiyo	12/07/1997	12/26/1997	√	√	√		Marlon Lewis
Southern Polar Front	10/19/1997	02/15/1998			√	√	Greg Mitchell

Cruise Location	Begin Date	End Date	On-board LAC	Over-flight Prediction	Near Real Time Imagery	Instrument Pool	Principal Investigator
HOTS Cruise	01/09/1998	01/12/1998	√	√			John Porter
Jamstec / Mirai	01/31/1998	02/11/1998	√	√	√		Marlon Lewis
SeaWiFS Initialization Cruise	01/26/1998	02/12/1998	√	√	√	√	Dennis Clark
Florida Bay	01/25/1998	02/07/1998	√	√			Eurico D'Sa
Antarctic	02/10/1998	03/18/1998		√	√	√	Greg Mitchell
Azores / Canary Islands	03/02/1998	03/27/1998	√	√			Marcel Wernand
Gulf of California	03/05/1998	03/16/1998	√	√	√	√	Jim Mueller
Gulf Of Maine	03/14/1998	03/27/1998	√	√	√		Bruce Monger
Indian Ocean	02/28/1998	03/15/1998	√	√			John Morrison
East China Sea	03/16/1998	03/27/1998	√	√	√		Gwo-Ching Gong
Bahamas	04/1/1998	04/07/1998	√	√		√	Robert Steward
HOTS	04/14/1998	04/16/1998		√	√		Craig Motell
Sicily Channel	03/27/1998	04/20/1998	√	√	√		M. Ribera d'Alcala'
California Coast	04/02/1998	04/24/1998		√		√	B.G. Mitchell
Yellow Sea	04/03/1998	04/23/1998	√	√	√		Sonia Gallegos
Sea Of Cortez	04/17/1998	04/26/1998		√	√	√	Gene Feldman
SW Pacific	03/24/1998	04/30/1998	√	√	√	√	Ajit Subramaniam
North Sea	04/6/1998	05/01/1998	√	√	√		Marcel Wernand
Atlantic Meridional Transect	04/6/1998	05/01/1998	√	√	√		Stan Hooker
Equatorial Pacific	04/26/1998	05/2/1998	√	√	√		Peter Strutton
Subtropical North Pacific	04/21/1998	05/06/1998	√	√	√		Jeffrey Polovina
HOTS	05/11/1998	05/15/1998		√		√	John Porter
Atlantic Ocean - Baltic Sea	05/01/1998	05/18/1998	√	√			Roland Doerffer
Gulf Of Cadiz	05/09/1998	05/19/1998	√	√			Andreas Neumann
Baltic Sea	05/26/1998	06/03/1998		√			Peter Land
Atlantic Meridional Transect	05/14/1998	06/18/1998	√	√	√		Stan Hooker
Gulf Of Maine	06/01/1998	06/15/1998		√	√	√	Bruce Bowler
Equatorial Pacific	06/6/1998	06/16/1998	√	√	√	√	Peter Strutton
Massachusetts Bay	07/05/1998	07/10/1998		√	√	√	Ajit Subramaniam
Labrador Sea	06/22/1998	07/10/1998		√	√	√	Glenn Cota
East China Sea	06/27/1998	07/08/1998	√	√	√		Gwo-Ching Gong
South China Sea	06/28/1998	07/03/1998	√	√			Hsien-Wen Li
Gulf Of Mexico	06/27/1998	07/03/1998			√		Andrew Thomas
Arctic Ocean	06/18/1998	07/20/1998	√	√			Dariusz Stramski
Resolute Bay	07/28/1998	08/25/1998	√	√		√	Glenn Cota
Equatorial Atlantic	07/15/1998	08/15/1998	√	√	√		C. Menkes
Long Island Sound	07/20/1998	07/30/1998		√			S. Papanikolaou
Puget Sound	06/04/1998	06/25/1998	√	√		√	Ron Zaneveld
Puget Sound	07/29/1998	08/22/1998	√	√		√	Ron Zaneveld
Arctic Ocean	08/05/1998	08/07/1998	√	√			Sergey Shirshov
Puget Sound	07/24/1998	08/22/1998	√	√	√		M.J. Perry
Taiwan Straits	08/10/1998	08/20/1998	√				Ming-Xia HE

Cruise Location	Begin Date	End Date	On-board LAC	Over-flight Prediction	Near Real Time Imagery	Instrument Pool	Principal Investigator
HOTS	08/08/1998	08/12/1998		√			John Porter
Gulf of Maine	08/14/1998	08/18/1998		√	√	√	Bruce Bowler
Se Bering Sea	08/15/1998	09/09/1998	√	√	√		Stephan Zeeman
South West Us	08/17/1998	09/25/1998	√	√	√		Edward Zalewski
South China Sea	09/11/1998	09/27/1998	√	√		√	Rick Miller
California Coast	09/13/1998	10/02/1998		√		√	Gregg Mitchell
North Pacific	08/30/1998	09/21/1998	√	√	√	√	Ron Zaneveld
HOTS	09/26/1998	09/30/1998	√	√			John Porter
North Pacific	10/01/1998	10/12/1998	√	√	√		Carrie Leonard
Atlantic Meridional Transect	9/14/1998	10/30/1998	√	√	√		Stan Hooker
Barents Sea	9/15/1998	10/10/1998	√	√			Oleg Kopelevich
Us East Coast	10/5/1998	10/13/1998		√	√		Stephan Howden
Gulf Of Maine	9/10/1998	10/31/1998	√	√	√	√	Bruce Bowler
HOTS	10/18/1998	10/20/1998		√			John Porter
East China Sea	10/15/1998	10/31/1998	√	√	√		Gwo-Ching Gong
Equatorial Pacific	10/23/1998	11/09/1998	√	√	√		Peter Strutton
HOTS	11/10/1998	11/12/1998	√	√			John Porter
South Atlantic Bight	10/27/1998	11/24/1998		√	√	√	Ajit Subramaniam
Gulf Of California	11/25/1998	12/09/1998	√	√	√	√	Andrew Barnard
Gulf Of Maine	12/02/1998	12/18/1998		√	√		Heidi Sosik
HOTS	12/13/1998	12/16/1998	√	√			John Porter
Indian Ocean	01/04/1999	02/23/1999	√	√	√		J. Le Fevre
Indian Ocean - INDOEX	01/14/1999	04/01/1999	√		√	√	Piotr Flatau
Southern Ocean	01/01/1999	04/01/1999	√		√		Steve Groom
California Coast	01/09/1999	01/31/1999		√	√		Greg Mitchell
SOIREE	01/01/1999	03/03/1999	✓		✓		Steve Groom
ANTARES4	0104/1999	02/23/1999	✓	✓	✓		J. Le Fevre
CalCOFI	01/09/1999	01/31/1999		✓	✓	✓	Greg Mitchell
BBOP/BATS124	01/11/1999	01/15/1999				✓	Dave Siegel
INDOEX	01/14/1999	04/01/1999	✓	✓	✓	✓	Piotr Flatau
FEB99SAB	02/10/1999	02/24/1999		✓		✓	Ajit Subramaniam
BATS Validation #25	03/02/1999	03/06/1999					Dave Siegel
EPS-A Test Flight	03/16/1999	04/29/1999		✓			J.H.M. Hakvoort
Baltic Sea	03/16/1999	03/16/1999		✓			Peter Land
Landsort Deep	03/30/1999	04/27/1999		✓			Peter Land
Bay of Biscay	04/01/1999	04/16/1999		✓	✓		Jean-Noel Druon
AR04-99	04/02/1999	04/10/1999		✓	✓		Douglas Phinney
HOTS	04/13/1999	04/15/1999	✓	✓			John Porter
N.Pac. Subtrop. Gyre	04/20/1999	05/08/1999	✓	✓	✓		Carrie Leonard
GOCAL99-A	04/21/1999	05/02/1999		✓		✓	Jim Mueller
AMT8	04/25/1999	06/07/1999	✓	✓	✓		Stan Hooker
OMEX 64PE138	04/26/1999	05/07/1999			✓		Marcel Wernand

Cruise Location	Begin Date	End Date	On-board LAC	Over-flight Prediction	Near Real Time Imagery	Instrument Pool	Principal Investigator
Japan Sea	05/01/1999	06/15/1999		✓	✓		Robert Arnone
Yarmouth-Portland	05/10/1999	10/01/1999		✓	✓	✓	Barney Balch
Helgoland	05/11/1999	06/13/1999		✓			J.H.M. Hakvoort
HX222 Inner Front	05/20/1999	06/20/1999		✓			Stephan Zeeman
HOTS	05/27/1999	05/31/1999		✓			John Porter
CARIACO	06/02/1999	12/20/1999	✓	✓		✓	Frank Muller-Karger
US East Coast	06/16/1999	06/22/1999		✓	✓		Stephan Howden
AREX-99	06/20/1999	08/05/1999		✓			Dariusz Stramski
OCE96-17680	06/23/1999	07/08/1999		✓	✓		Barney Balch
South China Sea	07/01/1999	07/31/1999	✓	✓		✓	Richard Miller
EQUALANT	07/06/1999	08/20/1999			✓		J. Etcheto
Chukchi Sea	07/07/1999	07/30/1999	✓	✓		✓	Glenn Cota
HOTS	07/12/1999	07/16/1999	✓	✓			John Porter
Gotland	07/14/1999	08/15/1999		✓	✓	✓	Peter Land
SML99	07/20/1999	07/23/1999		✓	✓		Heidi M. Sosik
Bay_of_Biscay	07/22/1999	09/15/1999		✓	✓		Jean-Noel Druon
Venice Tower Experiment	08/02/1999	08/06/1999	✓	✓		✓	Giuseppe Zibordi
CalCOFI	08/07/1999	08/29/1999		✓			Greg Mitchell
Heincke 99	08/24/1999	08/27/1999		✓	✓		Hans Barth
US East Coast	08/25/1999	10/15/1999		✓	✓		Stephan Howden
SEINESAT	08/25/1999	10/01/1999		✓	✓		Jean-Noel Druon
PROSOPE	09/04/1999	10/03/1999	✓	✓	✓		Stanford Hooker
OSCOPE	09/20/1999	10/30/1999	✓	✓	✓		Rik Wanninkhof
Aegean	09/22/1999	10/31/1999		✓			Sukru
SeaWiFS Validation Cruise #2	10/01/1999	10/21/1999		✓	✓		Dennis Clark
Black Sea	10/01/1999	10/31/1999		✓	✓	✓	Robert Frouin
AVARIS-CalCOFI	10/01/1999	10/31/1999		✓			Robert Green
CalCOFI	10/03/1999	10/31/1999		✓			Greg Mitchell
CAlCOFI-AVIRIS	10/1/1999	10/31/1999		✓			Robert Green
Cimar5	10/20/1999	11/14/1999	✓	✓	✓		W. Scott Pegau
TrichoToto	10/26/1999	11/29/1999	✓	✓	✓	✓	Ajit Subramaniam
GoCAL-99B	10/27/1999	11/08/1999		✓	✓	✓	Jim Mueller
BigEye Tuna Fisheries	11/15/1999	11/26/1999		✓			Carrie Leonard
Abbot_IDS	12/1/1999	12/1/1999			✓		Schieb
CalCOFI	1/06/2000	1/28/2000		✓			Greg Mitchell
Southern-Ocean	1/15/2000	03/14/2000		✓	✓	✓	Greg Mitchell
VOG_1	01/23/2000	01/30/2000			✓		John Porter
Bahamas_Experiment	02/10/2000	03/3/2000	✓	✓	✓		Stanford Hooker
AMLR_99_00	02//18/2000	03/16/2000		✓			Mati Kahru
Modycot	02/22/2000	03/11/2000			✓		Jean-Noel Druon
EcoHab_FLT_GoM	03/1/2000	03/9/2000		✓			Bob Swift
MODIS_MAB_FLT	03/10/2000	03/24/2000		✓			Bob Swift

Cruise Location	Begin Date	End Date	On-board LAC	Over-flight Prediction	Near Real Time Imagery	Instrument Pool	Principal Investigator
Venice_Tower	03/13/2000	03/24/2000		✓			Jean-Francois Berthon
MODIS_SAB_FLT	03/25/2000	03/27/2000		✓			Bob Swift
Florida _Coast	03/20/2000	04/30/2000		✓	✓		Standford Hooker
Optics_Eliat	03/22/2000	03/23/2000		✓	✓		Emmanuel Bonh
Projeto_Revizee	03/27/2000	04/4/2000		✓	✓		Aurea Maria Ciotti
AOL_GoM_Val_Flts	03/27/2000	04/21/2000		✓			Bob Swift
CalCOFI	04/2/2000	04/24/2000		✓		✓	Greg Mitchell
GOM2000	04/2/2000	04/15/2000		✓	✓		Richard Miller
Projeto_Revizee_2	04/7/2000	04/19/2000		✓	✓		Aurea Maria Ciotti
Belgica_2000_11	04/17/2000	04/19/2000		✓			Kelvin Ruddick
Projeto_Revizee_3	04/20/2000	05/7/2000		✓	✓		Aurea Maria Ciotti
TOTO 3	04/23/2000	04/28/2000		✓	✓	✓	Robert Steward
Scotia Prince Ferry 2000	04/12/2000	10/24/2000		✓	✓		William Balch
Belgica_2000_15	06/5/2000	06/7/2000		✓			Kelvin Ruddick
WFI Shelf	06/8/2000	12/31/2000			✓		Frank Mueller-Karger
Adriatic	23/06/2000	24/07/2000		✓	✓		Stan Hooker
Chukchi Sea	06/1/2000	07/30/2000	✓	✓			Glenn Cota
SW Florida	07/7/2000	07/21/2000				✓	Robert Steward
METEOR_M48	07/19/2000	10/11/2000		✓	✓		C. Shaefernet
OCE97_11168	08/4/2000	08/13/2000			✓		Bruce Bowler
Belgica_2000_24	10/2/2000	10/6/2000		✓			Kelvin Ruddick